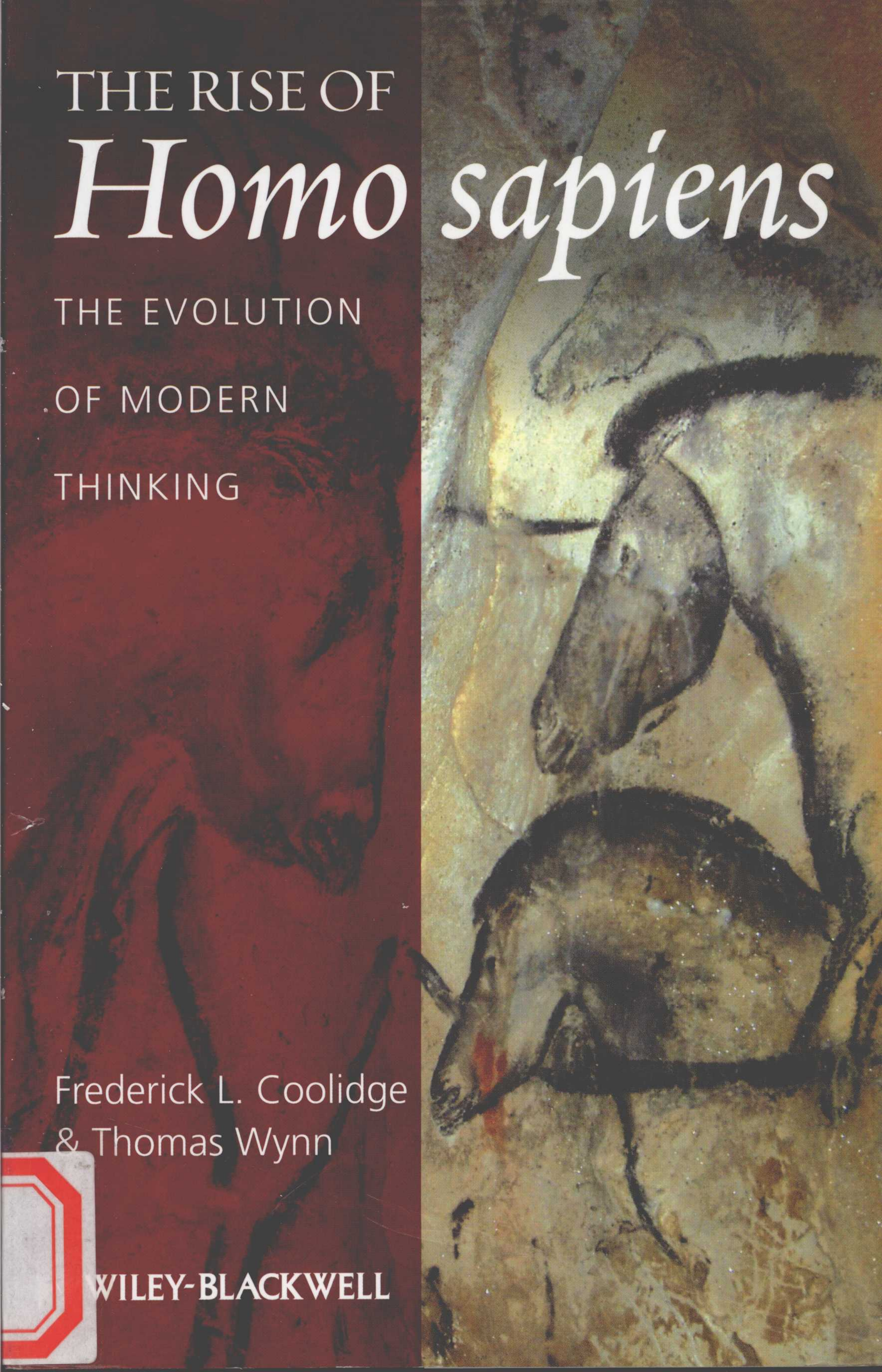
THE RISE OF *Homo sapiens*

THE EVOLUTION OF MODERN THINKING



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Introduction

Sometime about 25,000 years ago the last true Neandertal died, and with him or her a way of life that had successfully coped with the European world for over 200,000 years. True, the climate was changing, slowly deteriorating into full glacial conditions so that by 20,000 years ago Europe was colder than it had been in over 100,000 years. And the animals were changing; woolly rhinoceros and mammoth were fewer and harder to find. But Neandertals had adapted to environmental changes before, including a long, harsh glacial period between 180,000 and 130,000 years ago. They were tough, and well adapted to the vagaries of their European habitat. Something else had changed. A new and different kind of people had moved into Europe, beginning about 40,000 years ago. From our Neandertal's perspective they would have appeared odd – tall and skinny with child-like, bulbous heads, small noses, and ridiculous pointy chins. They were comparatively weak compared to Neandertals but, like Neandertals, they were effective killers of animals, large and small. However, unlike Neandertals, they preferred to kill from afar rather than get in close to spear their prey from short range. There were other differences that would have puzzled Neandertals: these people wore ornaments on their clothes and bodies and probably sat around their fires late into the night talking. They also crawled down into dark caverns and painted the walls with images of real and imagined creatures. For several thousand years these people shared the European continent with Neandertals, but eventually the Neandertals disappeared. This fate was shared by other humans when they, too, encountered these new people, who were, as the reader has no doubt deduced, modern humans.

Modern humans evolved in Africa, and beginning sometime after 70,000 years ago they began to leave their natal continent to colonize the habitable world. By 40,000 years ago, perhaps even earlier, they had colonized the island continent of Australia, a feat that required that they sail over the horizon, in boats, to a place that they could not directly see, accompanied by their mates, children, and dogs. By 15,000 years ago they had achieved an equally remarkable journey: they had sailed across the Pacific Arctic to colonize the continents of North and South America. No previous human had ever migrated so far, so fast. Whenever they encountered more archaic humans, in Asia and in Europe, the more archaic forms eventually disappeared, leaving *Homo sapiens* in sole possession of the planet.

What powered the success of these first modern humans? It was not technology; their stone tools were little different from those of Neandertals and other archaic humans. It was not a more powerful physique (they were actually rather weak), or a larger size, or a more efficient digestion, or indeed anything about their bodies. It was something about their minds, an ability that they possessed but that their cousins did not.

Executive Functions of the Frontal Lobes: A New Perspective on an Old Story

On September 13, 1848, an apparently responsible, capable, and virile 25-year-old foreman of a railroad construction crew, named Phineas Gage, accidentally dropped a $13^{1}/_{4}$-pound iron tamping rod on a dynamite charge. The resulting explosion drove the rod through the left side of his face and out the top of the frontal portion of his cranium. He was taken to his nearby hotel, which was to serve as his hospital room until 32 days later, when he was able to leave his bed. At this point, people noted that Phineas was eating well, sleeping well, and his long-term memories appeared to be intact. Seventy-four days after the accident, Phineas was able to return to his home 30 miles away. But there were discernible differences in Phineas's behavior, not related to his health, general intelligence, or memory. The original contractors who had hired him considered the "change in his mind" so great that they refused to rehire him. Phineas told his attending physician, J. M. Harlow (1868), that he could not decide whether to work or to travel. There were reports that Phineas was roaming the streets, purchasing items without his usual concern about price. About this same time, Harlow noted that Phineas's mind seemed "childish" and that he would make plans, change them capriciously, and then abandon them quickly. More importantly, Harlow wrote:

> Previous to his injury, though untrained in the schools, he possessed a well-balanced mind, and was looked upon by those who knew him as a shrewd, smart business man, very energetic and persistent in executing all his plans of operation. In this regard his mind was so radically changed, so decidedly that his friends and acquaintances said he was "no longer Gage." (p. 340)

In the psychological literature, the quote "no longer Gage" has more often become associated with Phineas's personality changes: his postmorbid use of profanity as well as depression, irritability, and capriciousness. Clearly, though, it seems that Harlow was associating Phineas's most important change to the loss of his once shrewd business acumen and his former ability in "executing all of his plans of operation." It must have been these latter abilities that originally made him valuable as a foreman. Significantly, Harlow's description may have been the first in the written literature for the frontal lobe metaphor: that the frontal lobes serve as a kind of executive that makes decisions, forms goals, devises strategies for attaining these goals, plans, organizes, and changes and devises new strategies when initial plans fail.

This executive functions model has been developed by a scientific discipline known as neuropsychology. This field provides explanations for brain and behavior relationships based on studies of brain-damaged patients, clinical populations with suspected brain dysfunction, and healthy people. Tests and measurements on the latter group help to define what normal or average functioning is so that behavior that deviates from standard functioning can be better defined. Neuropsychology is also broadly concerned with how the brain and its parts function and in identifying the symptoms of dysfunction.

One of the most prominent neuropsychologists of modern times was Russian Alexander Luria (1966), who wrote extensively about these executive functions of the frontal lobes. Luria noted that patients with frontal lobe damage frequently had their speech, motor abilities, and sensations intact, yet their complex psychological activities were tremendously impaired. He observed that they were often unable to carry out complex, purposive, and goal-directed actions. Furthermore, he found that they could not accurately evaluate the success or failure of their behaviors, especially in terms of using the information to change their future behavior. Luria found that these patients were unconcerned with their failures, and were hesitant, indecisive, and indifferent to the loss of their critical awareness of their own behaviors. Lezak (1982), a contemporary

American neuropsychologist, wrote that the executive functions of the frontal lobes were:

> the heart of all socially useful, personally enhancing, constructive, and creative abilities. Impairment or loss of these functions compromises a person's capacity to maintain an independent, constructively self-serving, and socially productive life no matter how well he can see and hear, walk and talk, and perform tests. (p. 281)

Welsh and Pennington (1988) defined executive functions in a neuropsychological perspective as the ability to maintain an appropriate problem-solving set for the attainment of a future goal. Pennington and Ozonoff (1996) view the domain of executive functions as distinct from cognitive domains such as sensation, perception, language, working memory, and long-term memory. Also, they see it as overlapping with such domains as attention, reasoning, and problem-solving "but not perfectly." (p. 54). They also add interference control, inhibition, and integration across space and time as other aspects of executive function. Their central view of executive function is a:

> context-specific action selection, especially in the face of strongly competing, but context-inappropriate, responses. Another central idea is maximal constraint satisfaction in action selection, which requires the integration of constraints from a variety of other domains, such as perception, memory, affect, and motivation. Hence, much complex behavior requires executive function, especially much human social behavior. (p. 54)

The ability to integrate across space and time or sequential memory function, is, no doubt, another salient feature of the executive functions. Successful planning for goal attainment would require the ability to sequence a series of activities in their proper order. Current neuropsychological assessment of executive functions invariably includes measures of planning, sequential memory, and temporal order memory (e.g., Lezak, 1995). It is also important to note that the frontal lobes have greater interconnectivity to subcortical regions of the brain than any other lobes of the cortex. The frontal lobes have extensive and reciprocal connections to the thalamus, basal ganglia, limbic system, and also posterior portions of the cortex (e.g., Bechara, Damasio, Damasio, and Lee, 1999; Furster, 1979; Luria, 1973; Gazzaniga, Ivry, and Mangun, 2002).

More recently, Goldberg (2002), who trained with Luria, claimed the development of the frontal lobes and its executive functions were the hallmark feature of the development of modern civilized behavior. In fact, he viewed the frontal lobes as the most "human" aspect of the brain. Not only, in Goldberg's opinion, do the frontal lobes conduct complex mental processes but they also appear to make our social and ethical judgments as well. Goldberg offered numerous pieces of evidence demonstrating how damage to the frontal lobe and its executive functions often results in chaotic, criminal, and antisocial behaviors.

Two Leaps in Cognition

Human cognitive abilities undoubtedly have a very long evolutionary history covering tens of millions of years. For most of this development, our ancestors were unremarkable in their cognitive abilities; as we shall see, they were just a group of bipedal African apes. But somewhere along the line they acquired cognitive abilities that set them clearly apart from their primate cousins. The fossil and archeological evidence suggests that there were two periods marked by especially significant cognitive developments, the first about 1.5 million years ago, and the second only about 100,000 years ago. We believe that the first major leap in cognition accompanied the evolution of an early member of our genus, *Homo erectus*, who developed a very different way of life that included movement away from the relative safety of wooded habitats, and expansion into a variety of new habitats. Within a relatively short evolutionary period (given the complete primate evolutionary history of over 50 million years) of less than half a million years, *Homo erectus* developed a dramatically new adaptation that included developments in spatial cognition and perhaps social cognition linked to changes in social life and landscape use. We think that this first leap in cognition may have been facilitated by physiological changes in sleep patterns tied to ground sleep.

Our second proposed leap in cognition led to completely modern thinking and occurred sometime between 100,000 and 40,000 years ago. In the archeological record this leap is even more dramatic than the first, and includes evidence for personal ornaments, art, elaborate ritual burials, complex multi-component technologies, and scheduled hunting and gathering organized months and years in advance. To explain this leap, we propose that a neural mutation occurred that led to a reorganization of the brain that enabled modern executive functions; specifically, we suggest an enhancement of working memory capacity, a cognitive ability originally defined by experimental psychologist Alan Baddeley (Baddeley and Hitch, 1974; Baddeley, 2001), and which has received voluminous experimental support over the past quarter-century.

This Book

And thus we return to the purpose of this book: an explication of the origins and evolution of modern thinking. We are not the first to tackle this problem; 17 years ago cognitive neuroscientist Merlin Donald (1991) wrote a provocative, neuropsychologically informed discussion in his *Origins of the Modern Mind*, and 10 years ago the archeologist Steven Mithen (1996) published a similarly provocative account in his *Prehistory of the Mind*. Also in 1996, psychologist William Noble and archeologist Iain Davidson published *Human Evolution, Language and Mind: A Psychological and Archeological Enquiry*. These books covered much the same ground that we intend to cover (and they took the best titles!), so it is reasonable to ask what justification there is for yet another book. First, there have been 10 to 20 years of additional research providing a wealth of new information. This is especially true in the area of neuropsychology and neuroanatomy; neuroscientists are finally beginning to understand how the brain works. The paleoanthropological picture is also clearer, enhanced by evidence from modern genetics, and new fossil and archeological finds. Second, our approach is rather different from earlier approaches in that it does not focus on language as the key to the modern mind, although we will address its role. Instead, our book focuses on a different component that we feel is equally important – the executive reasoning ability lost by Phineas Gage in such a spectacular fashion. Third, our book is co-authored by a psychologist and an archeologist. We have first-hand experience with trying to understand the peculiarities of one another's disciplines. We have found that what may seem obvious to one of us, may be a mystery to the other. This has sobered us to the task of writing a book on cognitive evolution that is both empirically based and accessible.

The book will begin with an introduction to the brain; we are both reductionists in agreeing that the brain is the source of an individual's thinking, and the logical starting place for any discussion of cognitive evolution. We will follow this with a brief discussion of brain evolution, and the methods of scientific investigation upon which the remainder of the book rests. Our actual documentation of human cognitive evolution will begin with non-human primates, after which we trace cognitive developments from early hominins through the final emergence of the modern mind.

2

The Brain

The purpose of this chapter will be to give the reader a solid understanding of the evolution and development of the brain and its functions. The study of the brain has ancient roots. Strong physical evidence of brain-behavior investigations comes from the process of trepanation, the intentional boring of a hole in the skull of a living person. Trepanned European skulls have been found dating back over 10,000 years and some 3,000-year-old trepanned South American skulls have also been discovered. The margins of the holes in many trepanned skulls indicate that the individual survived the ordeal, suggesting that trepanation was a carefully performed procedure. Because the first written records in many of the great early civilizations attached spiritual or demonic associations to abnormal behavior and the brain, it has been suggested that trepanation may have allowed the demons or evil spirits to escape. It is also possible that trepanation may have been used to treat headaches, epilepsy, or closed head injuries.

The earliest written evidence of investigations into the relationship between the brain and behavior comes from ancient Egyptians through hieroglyphics written on papyric paper as far back as 3,000 BC. These writings are amazingly advanced for their time. Some of the most valuable early Egyptian knowledge about the brain comes from the Edwin Smith surgical papyrus. The origins of the papyrus itself are largely a mystery. It was apparently buried with its last owner in about 1650 BC and plundered by nineteenth-century grave robbers. It was not fully translated until 1930 by University of Chicago Professor James Henry Breasted, who determined that it was a copy of a much earlier document that dated back another thousand years (about 2700 BC) to the age of the great pyramids. The translations of discoveries in the manuscript are breathtaking; the word "brain" was used for the first time in known human writings, the convolutions of the cortex (upper part of the brain) are likened to corrugations on metal slag, the meninges (thin, but tough, membranes covering the brain and enclosing the cerebrospinal fluid that nourishes the brain) are described, and the behavioral results of brain injuries are given, with reference to the side of the head that was injured and its effects upon the limbs. The papyrus showed that the Egyptians were well advanced in the science of medicine and surgery, even in the oldest kingdoms of Egypt.

The manuscript reports a series of medical cases. In one vivid description, the attending physician describes the first recorded case of what would come to be known as Broca's (a famous neurologist of the 1800s) aphasia. Aphasia is a speech or language disorder. In this particular case, the patient appears to be able to understand the physician, because the physician deemed it appropriate to inquire about the patient's malady. But the papyrus reads that the patient was speechless or voiceless yet he cried and wiped his tears during the questioning. Although there are now known to be many types of aphasia, Broca's aphasia is diagnosed when a patient has lost the ability to speak, although understanding and comprehension are spared. Frequently, Broca's aphasic patients become depressed, perhaps because speech comprehension allows them a fuller understanding of their disability. It is also curious that the physician noted that the patient wiped away his tears like a child might, and the physician noted that the patient "knows not that he does so." This addition does cast some doubt on the previous diagnosis. Were the patient's tears in response to the disability or were they random? Was the hand movement an automatic gesture? Did the physician inquire about the hand movements and, because the patient could not explain, did the physician conclude that there was limited awareness, like that of a child?

In another case within the manuscript, the physician noted that the patient's brain injury affected his body and limbs. In this case, the patient's skull had been shattered like an egg shell, although there was no specific external wound. The physician noted: "swelling protruding on the outside of that smash which is in his skull, while his eye is askew because of it; (and) he walks shuffling with his sole on the side of him having that injury which is in his skull."

This physician had begun to detect the phenomenon of localization, that is, linking specific parts of the brain to particular functions. In this case, however, the surgeon had probably been misled by the *contra coup effect*, where a blow to one side of the head propels the brain inside the skull to hit the opposite side of the skull (away from the injury site) with great force and, many times, the *contra coup* site exhibits greater dysfunction than the actual site where the skull was initially injured. Because it is now known that the right side of the body is controlled by the left hemisphere of the brain, and vice versa, the surgeon may have erroneously concluded same-side brain injuries resulted in same-side of the body paralysis.

Despite some very obvious mistakes by these ancient surgeons, the Edwin Smith papyrus stands as a monument to the beginnings of brain-behavior relationships no less than do the great pyramids or the Sphinx for archeologists. All of the previously noted contributions were remarkably sophisticated, particularly in light of how much was lost, forgotten, or misunderstood over the next 5,000 years.

Ontogeny of the Brain

The human brain develops rapidly and is visible within only three weeks of an egg's fertilization. There are four guiding principles in the brain's development: cell proliferation, cell migration, cell differentiation, and cell death (apoptosis – pronounced *a-poe-toe-sis*). As the fertilized egg divides itself repeatedly (cell proliferation), it begins to form a shape like a very small fried egg. This thickening in the center is called the embryonic disk. By the third week, a groove begins to develop along the length of the disk, and it forms the neural groove, which is the beginning of the spinal cord and brain. As the cells proliferate, they are genetically programmed to migrate to specific locations and subsequently develop specific forms (cytoarchitecture) and specific functions (cell differentiation). After the third week, the neural groove begins to close up and form the neural tube with holes that will eventually form the ventricles (spaces) of the brain. By the seventh week, the neural cells have proliferated, migrated, and differentiated enough to be clearly recognized as a brain (cerebrum or cortex), subcortex (below the cerebrum), and spinal cord structures.

Cell proliferation is mostly complete by about the twentieth week. Neural migration continues until about the twenty-ninth week. Cell differentiation and maturation (growth of axons and dendrites) continues until after birth. Surprisingly, however, both the neurons (brain cells) and its synapses begin a very precipitous decline after about one year of age and continue until about 10 years of age! This process is called apoptosis or programmed cell death. It is estimated that as many as 50 percent of the brain's neurons will die during this period and up to 66 percent of the established synapses will be eliminated. Thus, the final form of the brain is created much more like a sculpture than the creation of a building, with unnecessary pieces progressively removed over time.

The cerebral hemispheres

The most obvious visual landmark in a human brain is its two cerebral hemispheres, which together are also referred to as the cortex. The left hemisphere is actually slightly bigger than the right, both in humans and great apes (like chimpanzees and gorillas), and in humans the potential for each hemisphere is different: the left hemisphere in humans will be devoted to the processing of language and the right hemisphere will be concerned with non-verbal and visual-spatial functions, although the two hemispheres interact on nearly all of these functions. After puberty, the two hemispheres will lose much of the plasticity (ability to handle different functions) that enabled them to take over each other's functions. Thus, if a left hemispherectomy (*-ectomy* means *removal*) was performed on a post-pubertal human, that person would be essentially mute with very limited language abilities. Before puberty the right hemisphere could learn some but not all language functions, but after puberty this plasticity would be lost.

The two hemispheres are separated by a major fissure running from anterior (front) to posterior (back). They communicate rapidly by means of a commissure (communicative connective tissue) called the corpus callosum. The corpus callosum lies beneath the dorsal (top) surface of the cortex. Because of this location, the corpus callosum is considered a subcortical structure.

The interior of the brain is separated by four major ventricles, which are filled with cerebrospinal fluid that nourishes the brain with nutrients like oxygen. The cerebrospinal fluid is created by the brain surfaces forming the ventricles, and it flows like a river over the interior surfaces and then is reabsorbed. Its flow is aided by tiny cilia lining the ventricles. If the flow is blocked, the resulting syndrome is hydrocephalus (*hydro* meaning *water*, and *cephalus* meaning *brain*), which causes brain malformation and growth failure if it occurs in infants. The shunting or siphoning of this fluid reduces the cerebrospinal fluid pressure and ameliorates the hydrocephalic condition.

The cortical surface of a living brain is actually reddish-brown in color. Its surface is gray in a laboratory or dead brain, hence, the name *gray* *matter*. Beneath the surface of the cortex, it is substantially white because the myelin sheath lining the axons of brain neurons is made up of fatty matter, hence, the name *white matter*. The fat speeds up the transmission of nerve impulses. Thus, demyelinating diseases, such as multiple sclerosis, interfere with motor activity, and motor slowing is its major initial symptom.

Lobes of the cortex

The frontal lobes: motor cortex

The frontal lobes are the largest most clearly demarcated of all of the lobes of the brain. Their inferior (lower) convolutions are bordered by the lateral or Sylvian fissure (a deep indentation). Their posterior convolutions, which border the parietal lobes, are formed by the central sulcus (a less deep indentation than a fissure). See figure 2.1 for more details.

One of the first models of brain function was developed by two German physiologists, Fritsch and Hitzig, in 1870. This model, based upon their work with dogs, is still roughly used today. It noted that the area just anterior to the central sulcus appeared devoted to motor movements, and thus was labeled motor cortex. The area posterior to the central sulcus (thus, in the parietal lobes) was called sensory or somatosensory cortex. When stimulated, the other areas were "quiet," so they became known as

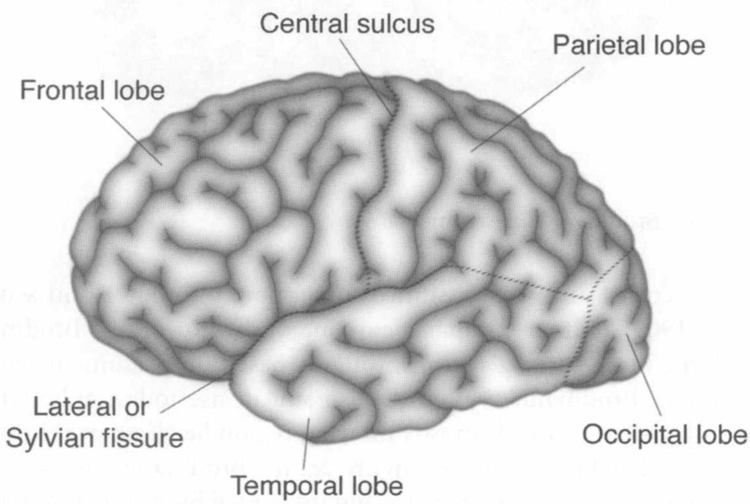

Figure 2.1 Lobes of the cerebral cortex (lateral view)